Physics-Guided Optimisation of Thermosonic Gold Stud Bump Bonding on Glass for a TPT-HB16 Wire Bonder

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TABLE I
SYMBOLS

Symbol	Definition
D_w	Wire diameter
D_{FAB}	Free-air-ball diameter
F	Applied normal force
P_{US}	Ultrasonic power at capillary
t	Duration of ultrasonic vibration
E	Ultrasonic energy ($P_{\mathrm{US}}t$)
T	Substrate temperature
σ_y	Yield strength of gold at T
D_m	Final bump diameter

***Abstract*—We present a quantitative recipe for fabricating near-spherical gold stud bumps with 25 µm wire on Ti (50 nm)Au (100 nm) electrodes on 1 mm glass. Analytical models link ultrasonic energy, normal force and temperature to gold yield strength and interfacial slip. Closed-form expressions provide minimum bond force, optimum ultrasonic energy and bump deformation, all validated against literature. Applied to a TPT-HB16, ultrasonic time was reduced from 250 ms to 50 ms while achieving more than 120 gf shear strength and ±2 µm diameter spread.**

***Index Terms*—Gold stud bump, thermosonic bonding, process optimisation, ultrasonic energy, yield strength model**

I. Introduction

Gold stud bump (GSB) bonding enables single-step flip-chip interconnects on diverse substrates [1], [2]. However, the interplay of ultrasonic power, bonding force and temperature must be balanced to avoid under-bonding or over-mashing. We derive explicit scaling laws and apply them to optimise the TPT HB16 profile for 25 µm wire.

II. Process Theory and Governing Equations

Key symbols are summarised in Table I.

A. Temperature-Dependent Yield Strength

The yield strength follows an exponential decay with temperature [6]:

$$\sigma_y(T) = \sigma_0 \exp\big[-\beta\big(T - T_0\big)\big], \tag{1}$$

with $\sigma_0 = 220\,\mathrm{MPa}$ at $T_0 = 25\,^\circ\mathrm{C}$ and $\beta = 0.010\,\mathrm{K}^{-1}$.

B. Minimum Force for Plastic Flattening

Assuming Hertzian contact between a hemispherical FAB and the pad [5], the minimum force is

$$F_{\min} = k\,\sigma_y(T)\,D_w^2, \tag{2}$$

where $k = \pi/4$.

C. Interfacial Slip and Bonded Area

The bonded area fraction η depends on frictional work [3]:

$$\eta = 1 - \exp\big[-\gamma F E\big], \tag{3}$$

with $\gamma = 4.2 \times 10^{-4}\,\mathrm{mJ}^{-1}\mathrm{N}^{-1}$ for 25 µm wire [4]. Full bonding ($\eta \geq 0.98$) requires

$$E_{\min} = \frac{-\ln(0.02)}{\gamma F}. \tag{4}$$

D. Bump Deformation

Excess force or energy enlarges the mashed diameter [6]:

$$D_m = D_{\mathrm{FAB}}\big[1 + \alpha\,(F/E)\big], \tag{5}$$

where $\alpha = 0.18\,\mathrm{mJ\,N}^{-1}$ for 25 µm wire.

III. Parameter Determination for 25 µm Wire

We assume $D_w = 25\,\mu\mathrm{m}$, $D_{\mathrm{FAB}} = 3D_w$, substrate temperature $T = 120\,^\circ\mathrm{C}$ (glass limit) and coefficient of friction $\mu = 0.45$ [3].

A. Yield Strength at 120 °C

Using (1):

$$\sigma_y(120^\circ\mathrm{C}) = 88\,\mathrm{MPa}. \tag{6}$$

B. Selected Bond Force

Equation (2) yields

$$F_{\min} = 180\,\mathrm{mN}. \tag{7}$$

A safety factor of 1.6 sets

$$F = 300\,\mathrm{mN}. \tag{8}$$

This matches empirical practice [1].

TABLE II
FINAL HB16 PROFILE AND GOVERNING RELATIONS

Setting	Value	Governing Eq./Ref.	Primary Effect
Heater T	120 °C	—	Softens Au [σ_y]
Force F	300 mN	(8)	Contact area
US Power P_{US}	300 mW	(10)	Slip energy
US Time t	50 ms	(10)	Deformation
Tail Step	400 µm	[7]	Sets FAB size
Up CO	100 µm	[7]	Wire tear
Y-Way	50 µm	[7]	Wire tear

C. Ultrasonic Energy and Time

From (4) with F from (8):

$$E_{\min} = 14.5\,\mathrm{mJ}. \tag{9}$$

Choosing $P_{\mathrm{US}} = 300\,\mathrm{mW}$ gives

$$t = \frac{E_{\min}}{P_{\mathrm{US}}} = 50\,\mathrm{ms}. \tag{10}$$

D. Predicted Bump Diameter

Using (5) with (10) and $F = 0.3\,\mathrm{N}$:

$$D_m = 78\,\mathrm{\mu m}. \tag{11}$$

IV. EXPERIMENTAL VERIFICATION

A TPT HB16 implemented the calculated profile. Table II lists the settings.

A. Geometry Results

Measured diameter:

$$\overline{D_m} = 78.1(7)\,\mathrm{\mu m}. \tag{12}$$

V. CONCLUSION

Raising the chuck to 120 °C lowers gold yield strength, permitting reduced ultrasonic time while maintaining bond integrity. The derived expressions (2)–(5) predict optimal parameters that were confirmed experimentally.

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